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Large Aperture Quantum Well Shutters for

Fast Retroreflected Optical Data Links in Free Space

by

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ABSTRACT

This paper reports progress on the development of a fast modulating retroreflector for a free space optical data link. A previous publication reported sustaining video over a 17 meter link using a multiple quantum well shutter with a diameter of 0.5 cm at a rate on the order of 0.5 Mbps, limited by the demonstration electronics. This work describes improvements in the device performance, which is on the order of 4 Mbps to 6 Mbps with a Bit Error Rates of 10^{-6} over a robust optical link. This device lends itself to an array configuration for long range applications and will clearly support T1 rates of 1.54 Mbps, and higher.

I. INTRODUCTION

There is ongoing interest in methods to reduce payload envelopes and power requirements for communications for both spaceborne and airborne platforms. When an inherently fast shutter is coupled with an optical retroreflector, the resulting device can significantly reduce payload weight, volume, and power consumption compared to radio frequency and conventional optical communications configurations[1]. To implement such a device effectively in the architecture described here, a space-based, airborne-based, or ground-based laser interrogates another platform with a continuous wave (cw) beam or with a bit stream with long pulsewidths. The approach we have adopted is to couple a retroreflector with a multiple quantum well (MQW) shutter mounted on the interrogated platform. The shutter is absorptive in nature and it modulates the light with on-off keying to produce a bit stream which is retroreflected back to the interrogating platform. The basic concept is illustrated in Figure 1. Two way communications can be readily implemented by pulsing the interrogation laser at a rate and with a pulsewidth which can essentially enable burst communications on the return beam.

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When an array of modulators coupled with retroreflectors are used, as illustrated in Figure 1, the need for a gimballed telescope for pointing and tracking is obviated due to the increased field-of-view from the array. Such an array could be on the order of 300 grams, with an estimated volume of about 15

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cubic centimeters, and requires a drive power of 0.5 W to 2 W depending on the number of modulators used. These substantially reduced requirements for the onboard optical communications payload are particularly relevant in light of the current interest in developing very small satellites and the utilization of small airborne vehicles.

The concept of a modulating retroreflector is not new but until recently, materials for the shutter have not been able to sustain data rates in the Mbps regime [2]. With the advent of Multiple Quantum Well technology, a potentially fast shutter is possible [3]. This technology currently supports very fast links for the fiber optics community. The speed of the MQW shutter is limited by its RC time response. For this reason, a shutter with a very fast rate can be constructed due primarily to the small apertures required for fiber applications. Recent developments in device technology are enabling increased aperture diameters. Previous work described progress in the use of such large aperture MQW technology combined with optical retroreflector array techniques to transfer a video stream over a 17 meter free space link using a laser diode and avalanche photodetector [4]. In that effort, the link transferred video at a rate of approximately 0.5 Mbps and 3 video frames per second. The rate of transfer was limited by the demonstration electronics not the device itself.

This paper reports results of Bit Error Rate (BER) testing of a transmissive and reflective MQW shutters coupled with standard optical retroreflectors. Using a BER of 10^{-6} which is typically acceptable in a given link, devices performed at a rate of 4 Mbps and 6 Mbps respectively in the non-photon limited case using a 4 mm diameter MQW shutter. Recorded waveforms indicate that with signal processing, bit extraction may be possible for higher rates if desired.

II. EXPERIMENT

For this series of experiments, a psuedo-random code generated by a BER tester drove the appropriate voltage signal to a comparator and then to a MQW shutter over a programmed range of baud rates. Two basic types of shutters, a reflective and a transmissive device, were each coupled to a standard optical retroreflector. The device was illuminated over free space using a laser diode of the appropriate wavelength. The light was attenuated to different levels depending on the response under test. The retro-reflected bit stream was directed to an Avalanche Photodiode (APD). The signal was then amplified using a wide-band amplifier and conditioned with a simple comparator circuit before being directed to the receive signal port of the BER tester. Figure 2 illustrates the bench configuration. It can be seen from this figure, that the transmissive modulator requires a different laser diode and optics.

The reflective MQW device performed optimally in a the region of 855 nm to 860 nm, depending on the bias. It was operated at 856 nm. The transmissive device, which was somewhat more straightforward to implement on the bench, operated in the region of 975 nm to 985 nm and was operated at 976 nm. In both cases, a laser diode was selected to radiate at the wavelength required.

In the reflective modulator experiments, the laser diode was operated in the temperature-current window of greatest stability to avoid mode-hopping. No mode-hopping-related problems occurred in the transmissive modulator experiments since a grating-stabilized laser diode was used.

Device response was tested for robust optical links under a variety of conditions. Contrast ratio as a function of drive voltage was determined by varying the bias required to drive the respective devices. BER response was measured as a function of bits per second. The tester itself, provided digitized clocked differences and BER read-outs, which were later used in analysis. Waveforms were also recorded using a digitizing oscilloscope.

II. RESULTS

Bit Error Rate is the standard Figure-of-Merit for a communications link. A BER of 10^{-6} is generally considered to be acceptable. In a configuration using a modulating retroreflector array, BER is inherently limited by the contrast ratio of the device. This parameter, which is defined as the ratio of the On to Off signals, was measured as a function of drive voltage in the two different devices. Results are shown in Figure 3. From the figure, it can be seen that for the samples tested, the contrast ratio of the transmissive modulator was less than that of the reflective device. In both cases, drive voltages on the order of 5V to 10V provide biases high enough to sustain high BER values over a robust link. Specifically, for a 6 Mbps link at a drive voltage of 5V, the required power for the reflective modulator and driver was 40 mW. Similarly, for the transmissive modulator operating at 4 Mbps and 10 V, the required power was found to be 170 mW.

For the optimum drive voltage for a given device, the BER from the modulator and retroreflector was measured as a function of bit rate. Figures 4 and 5 show results for the reflective and transmissive architectures, respectively. For a robust link, i.e., for a link which is not photon-limited, bit rates of over 6 Mbps were possible while still maintaining a BER of 10^{-6}. It is important to note here that the BER drops only because we are approaching the RC response time of the device. Figure 5 shows a similar curve for the transmissive device.

At the low photon levels characteristic of a communications link the BER will be determined by the signal level, the noise in the detector and the contrast ratio of the modulator. This is shown in figure 6 which shows the BER vs. modulator voltage for the transmissive device operated at 1 Mbps at a signal level at which the detector noise was comparable to the signal level. The BER improves as the voltage increases due to a commensurate increase in the contrast ratio.

III. CONCLUSIONS

In this paper, we have reported progress in the development of a modulating retroreflector which can support data rates on the order of 4 Mbps to 6 Mbps. A wide-aperture Multiple Quantum Well shutter was coupled with a standard optical corner cube to optically transfer data over a free space link on the experimental bench.

Two architectures were investigated. The first used a transmissive device which absorbed optimally in the 980 nm regime. This device was easier to implement on the bench and will lend itself to straightforward configurations on a given payload. The reflective device was operated in the 850 nm regime. Measurements on this device indicate greater contrast ratio at lower drive voltages, thus enabling higher bit rates for a given BER of 10^{-6}.

Although the power required to drive the transmissive device under test was a little more than 3 times that required for the reflective device, the power is still very low. Anticipated power requirements for a satellite or other small platform would be less than 200 mW for a single device and no more than 3 Watts for a 15 device array.

No compression techniques, error corrective coding techniques, or signal processing were implemented in the experimental procedures and analysis. There is likely a combination of techniques that would enable faster response for a given MQW shutter coupled with a retroreflector. Future work will involve investigation into array configurations and payload packaging for a small platform to be interrogated from the ground.

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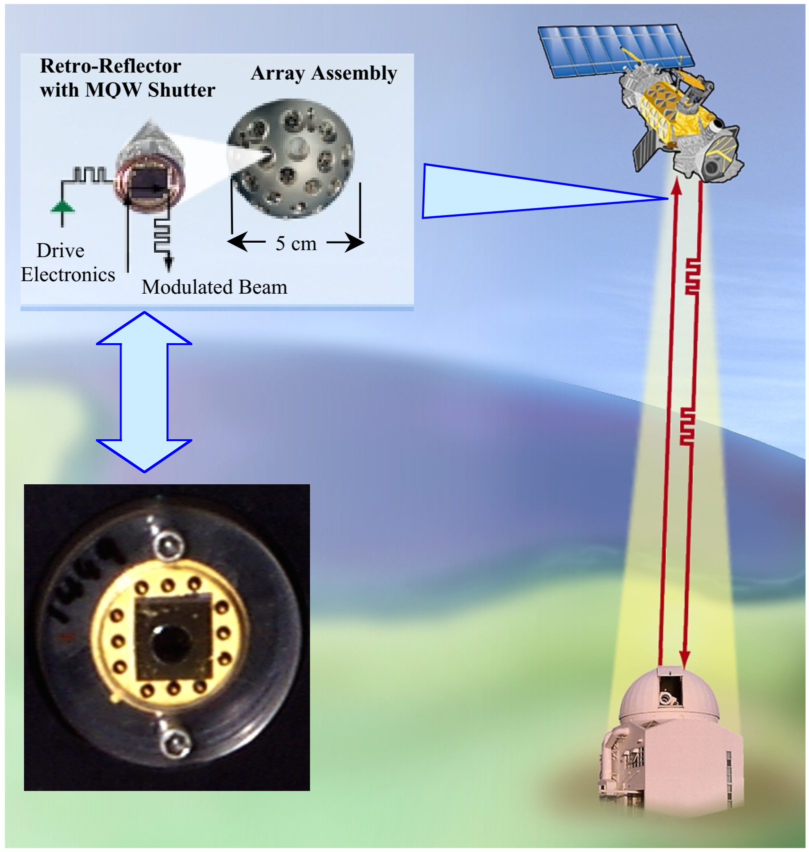

FIGURE 1. Ground-to-Space Concept for use of a modulating retroreflector array using Multiple Quantum Well technology for fast optical data links in free space.

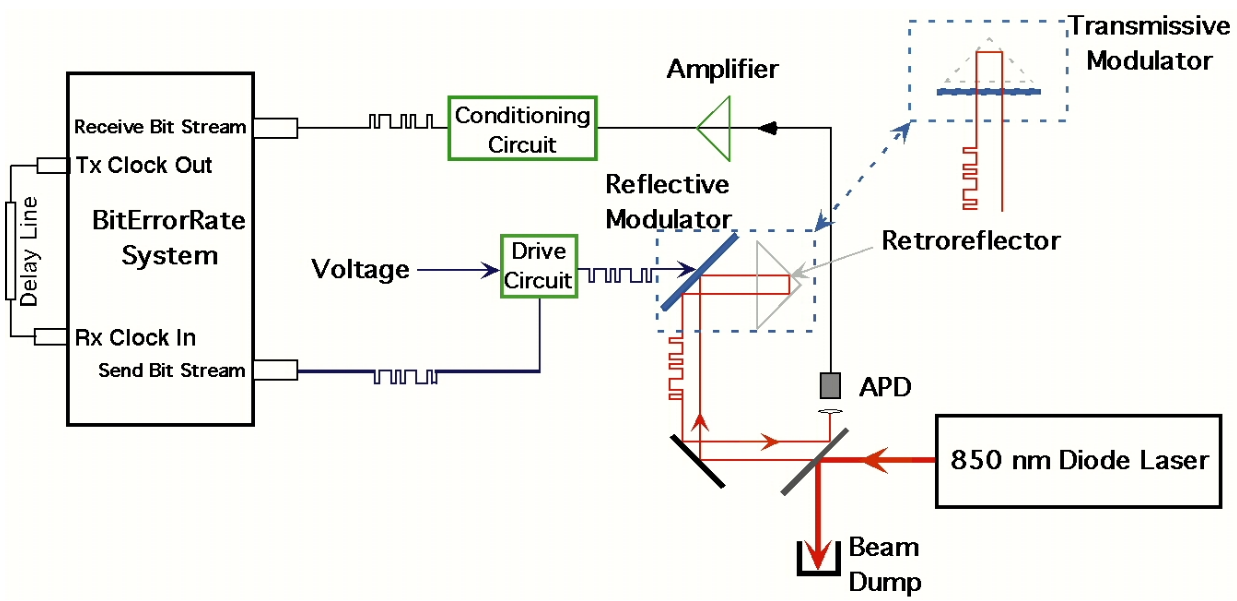

FIGURE 2. Bench configuration used to test BER response of a MQW modulator coupled with an optical retroreflector. A different diode tuned to the peak absorption of the shutter used was implemented depending on whether a transmissive or reflective device was being tested.

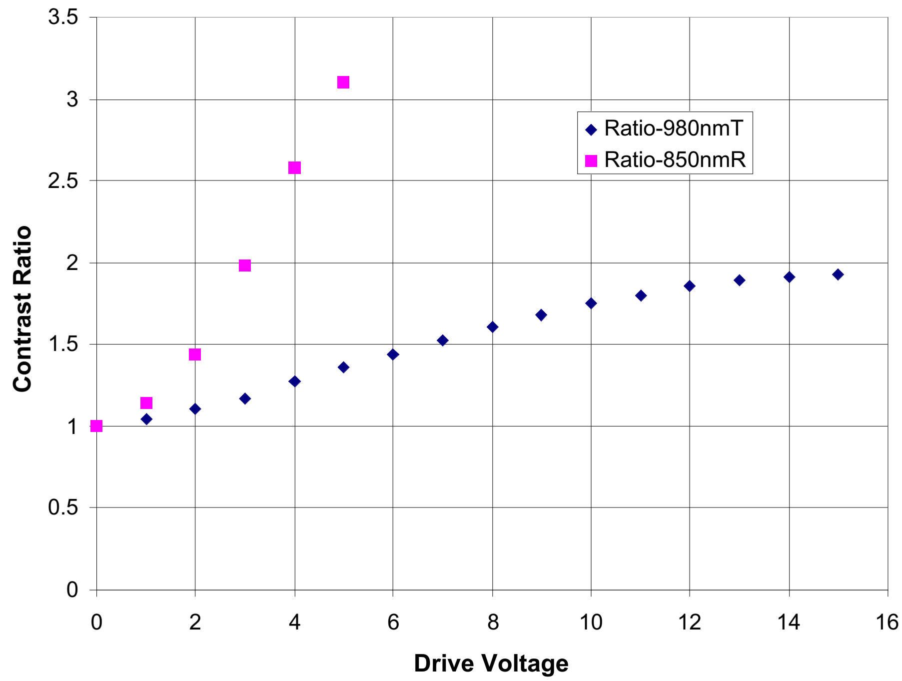

FIGURE 3. ON/OFF ratio as a function of drive voltage for two different MQW retroreflector architectures.

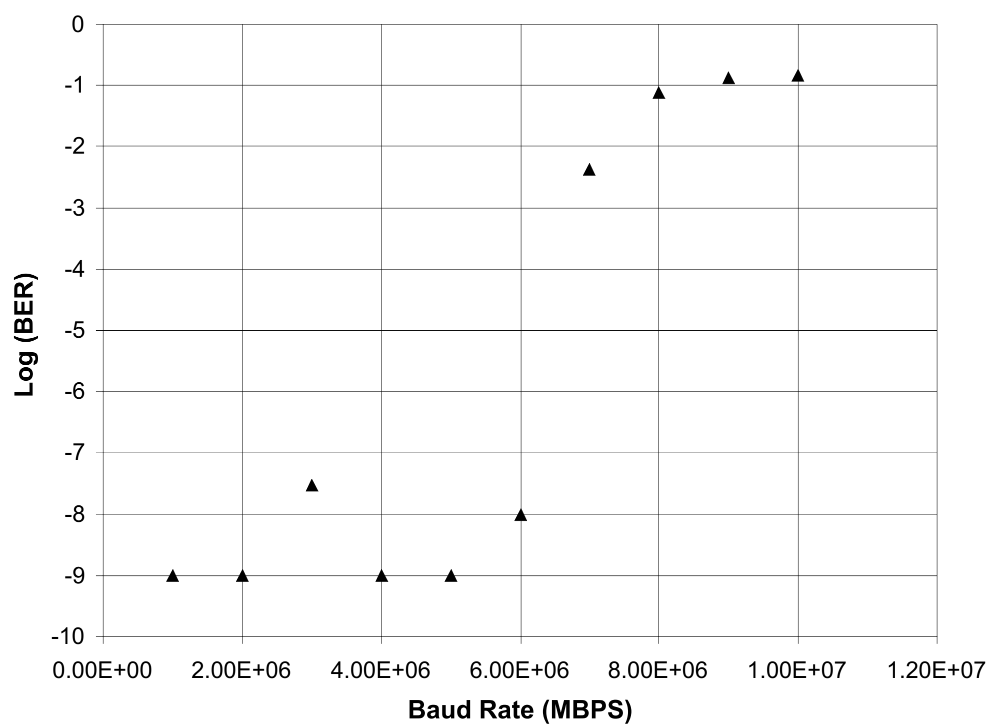

FIGURE 4. BER as a function of baud rate for an incident photon power level of 10 µW for the 4 mm MQW reflective device at 856 nm.

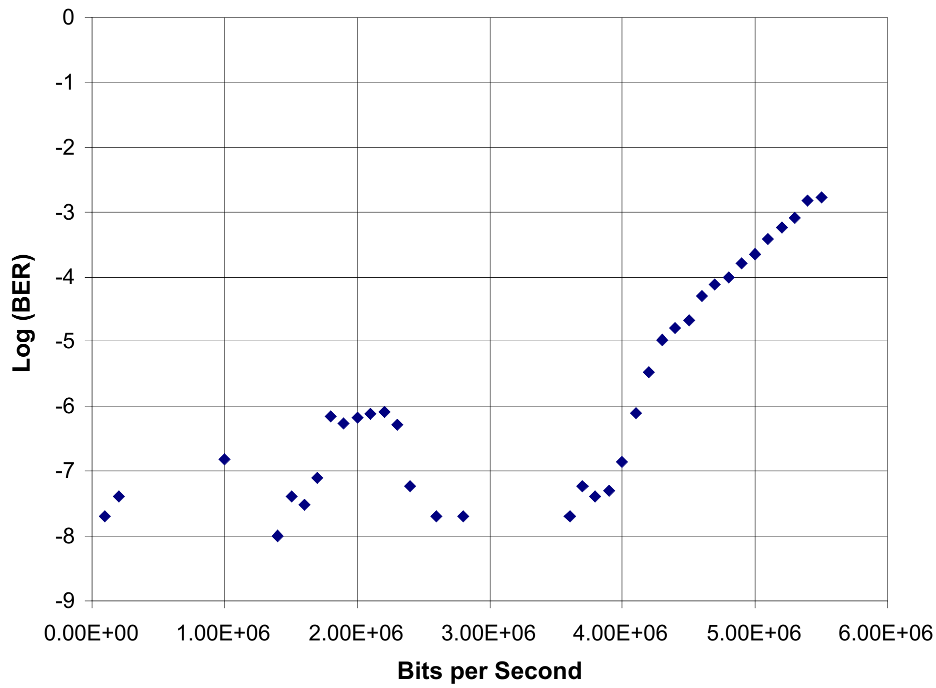

FIGURE 5. BER as a function of bits per second using the 4 mm MQW transmission architecture at 976 nm.

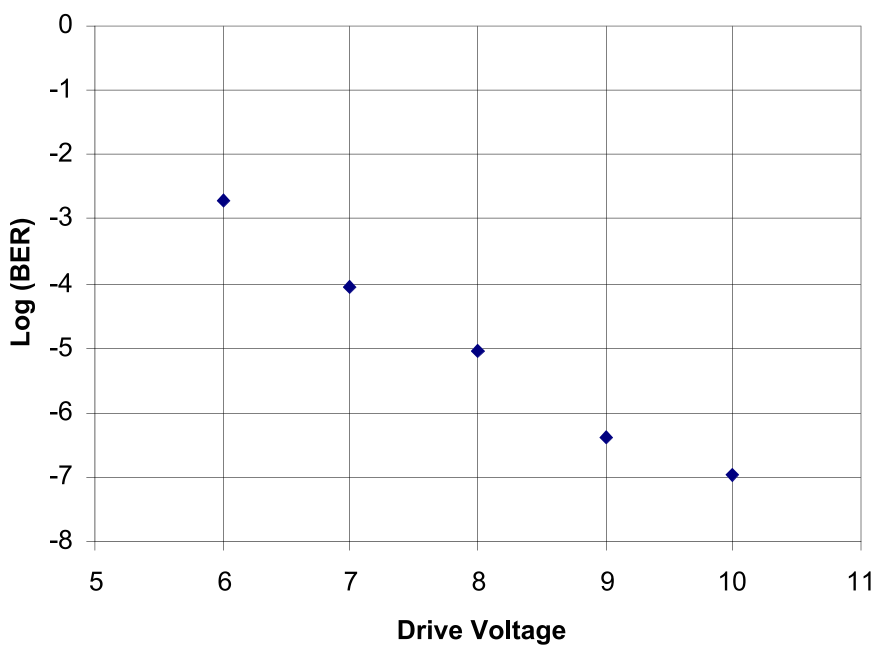

FIGURE 6. BER as a function of modulator drive voltage for the 976 nm MQW transmissive device at a modulation frequency of 1 Mbps.